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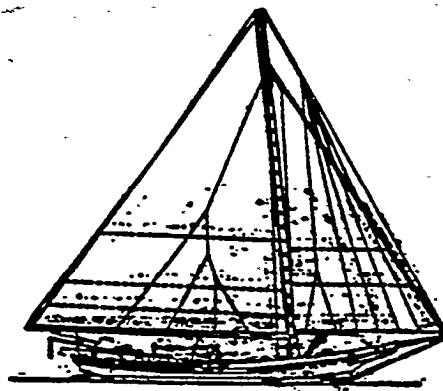
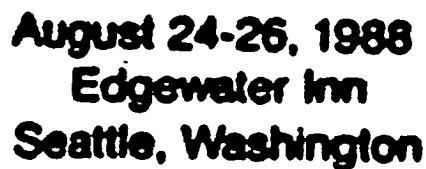
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A Group Technology Approach to Master Scheduling of Shipbuilding Projects

No. 8B

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This paper describes the current Master Scheduling approach used at National Steel and Shipbuilding Company (NASSCO) in San Diego. Master schedules at NASSCO focus on key interim products involved in ship construction: units, blocks, (on-board) zones, and tests. Network scheduling algorithms (i.e., Critical Path) are used. Each interim product has an associated subnet. Categorization by type is used to simplify the task of developing and maintaining activity lists, dependencies (predecessor/successor relationships) and durations for the thousands of activities. Manual level-loading of critical resources is incorporated into and supported by the overall scheduling process. The paper includes some discussion of problems encountered in the implementation of this scheduling approach.

NOMENCLATURE

The following definitions are provided to clarify usage within the body of this paper. They reflect common usage within National Steel and Shipbuilding, San Diego. Definitions provided are not intended to imply industry standard practice.

The definition of interim products is somewhat circular. The intent behind defining interim products is to focus attention on a deliverable units of work having common process characteristics, in the spirit of the definition of Group Technology given below.

Block -- a structural assembly which will be erected singly or as part of a grand-block;

Group Technology -- organization of work to take advantage of common process characteristics, while accommodating minor differences in material, geometry and size, in order to bring the advantages of mass production to high-variety, mixed quantity production;

Interim Product -- an assembly or portion of work which can be logically scheduled and managed as though it were a deliverable product; e.g., unit, block, subzone, system test, etc.;

Pallet -- subdivision of a workpackage; a unit of work which has common work characteristics (process, tooling or material), and which can be performed by a single crew in a reasonably short period of time while working in a defined work area;

Subzone -- a geographic volume within a ship; typically bounded by watertight bulkheads fore and aft, decks above and below, and shell plating to port and starboard;

Unit -- piping unit; an erectable assembly composed both of structural components (structural framework, common foundations, floor plates and gratings) and outfitting components (e.g., pumps, motors, piping, gauges) and which is not an integral part of the ship structure;

Workpackage -- all work within a given stage of construction, of a given type of work (e.g., piping, vent, etc.), and for a given interim product (unit, block, subzone, etc.).

INTRODUCTION

This paper describes a method of developing the portion of the Master Production Schedule (MPS) associated with the assembly, outfitting and erection of hull blocks. The method discussed:

- o uses information available very early in the contract cycle
- o can accommodate some inaccuracy in available information
- o is sufficiently detailed to insure workable schedules
- o integrates the scheduling of engineering, material procurement, detail planning and production activities
- o uses Group Technology concepts and PC-based Project Management software to maximize efficiency of the scheduling process

The method discussed can, by extension, be applied to other portions of the Master Production Scheduling process.

MASTER PRODUCTION SCHEDULE

The American Production and Inventory Control Society dictionary defines the Master Production Schedule in part as follows:

"...the anticipated build schedule for those selected items assigned to the master scheduler...." 1

The Master Production Schedule for an individual ship or contract must take into account the contractual requirements, existing or anticipated backlog, availability of drawings and material, availability of manpower and capacity, and management objectives. The Master Production Schedule must therefore include or incorporate information from:

- o Milestone/Key Event Schedules
- o Procurement Master Schedule
- o Engineering Master Schedule
- o Manpower Curves and Capacity Plans

The Master Production Schedule integrates the efforts of different functional areas (production, engineering, materials) as well as various production sub-organizations (steel fabrication, assembly and erection, outfitting shops, on-block and on-board outfitting, test and trials, and subcontractors,). Different parts of the organization require different information. The shop requires a set of need dates, together with design and material availability dates. On-block outfitting requires steel assembly complete dates, design and material (purchased and fabricated) availability dates, and erection dates. The MPS provides the sets of dates necessary to do this, while allowing area managers flexibility to schedule within the required constraints. The responsibility to manage must rest with the manager, not the scheduler.

The Master Production Schedule becomes the basis of more detailed scheduling of engineering work, material procurement, manpower planning, training schedules, and capacity planning. Development of the Master Production Schedule therefore assumes a degree of urgency once a contract is awarded.

Methods must be developed which provide reasonable accuracy of schedule even when based on preliminary and incomplete information. Later changes to the MPS which result in earlier requirements for material or engineering products are difficult or impossible to accommodate. On the other hand, schedules which

introduce unnecessarily early requirements on engineering and material procurement work may result in higher costs for those functions.

GROUP TECHNOLOGY AND INTERIM PRODUCTS

The concepts of Group Technology are central to much of the modernization of shipbuilding production management methods and procedures. Application of these concepts within the shipbuilding environment has been well-documented within the shipbuilding literature.

Group Technology (GT) has been defined as:

"GT is a technique for manufacturing small to medium lot size batches of parts of similar process, of somewhat dissimilar materials, geometry and size, which are produced in a committed small cell of machines which have been grouped together physically, specifically tooled, and scheduled as a unit." 2

While such a definition works well in a machine shop environment, a modified definition is required for effective application to shipbuilding. The following definition by G. M. Ranson is suitable:

"The logical arrangement and sequence of all facets of company operation in order to bring the benefits of mass production to high variety, mixed quantity production." 3

Ranson's definition broadens the scope of application of the central concept of Group Technology: focusing on similarities in process, while accommodating differences in materials, geometry and size. This broader definition encompasses much of the work that has been done in applying GT to the shipbuilding environment. The key to successful application of Group Technology in shipbuilding is a focus on "interim product."

Ship construction is characterized by a single, deliverable end product. The ship is assembled from a number of major assemblies (structural hull blocks, main engines, shafting, piping units, etc.) supplied by the shipyard and by outside vendors. These in turn are composed of smaller assemblies and purchased components. The bill of materials explosion of a ship being built using modern shipbuilding technology would have levels similar to those shown below:

```

      ship
      |
      major assemblies
      (e.g., blocks, units, subzones, main
      engines, shafting)
      |
      minor assemblies
      (e.g., manifolds, structural panels,
      pumps, vent fans)
      |
      fabricated and purchased parts and
      components
      (e.g., pipe spools, vent pieces,
      valves, connection boxes)
      |
      raw stock material
      (e.g., plate, angle, pipe, cable)

```

At the middle levels of the ship assembly process, a variety of interim products can be defined. For example, at the major assembly level these include: piping units, outfitted structural blocks, outfitted subzones and tanks, shafting installation, etc. (Terminology varies somewhat within the shipbuilding industry.) Focusing on these interim products is the key to application of Group Technology to the shipbuilding process.

This article will focus on the scheduling of a particular interim product at the major assembly level: assembly, outfitting and erection of structural hull blocks, including the design and material need dates for each block. The scheduling approach discussed is applicable with minor modifications to other interim products at the major assembly level.

HULL BLOCK SCHEDULING ELEMENTS

Scheduling of all work associated with structural hull blocks was done using Project Management software running on an IBM AT computer. A project network was built for the purpose which included:

- o engineering activities
- o material identification, procurement and receipt
- o detail planning activities
- o all related production activities

The purpose was to integrate schedules at a level of detail sufficient to assure a workable schedule.

Building the scheduling network involved merging several pieces of information:

- o a scheduling network for a typical block which integrated the engineering, materials, planning and production activities associated with the block
- o a hull block breakdown showing the location of the structural breaks between blocks

- o an erection schedule showing erection dates for all outfitted structural blocks
- o tables of scheduling offsets and schedule durations for those activities and relationships which vary according to block type or individual block

These elements, from which the overall network schedule is built, will be discussed in turn.

Hull Block Network

The hull block network includes known scheduling information common to all blocks. Dependencies among and between engineering, materials, planning and production activities are incorporated. Desired lag periods between activities are included. Schedule durations which are standard for all blocks are incorporated. The activities and relationships represent the flow of materials and information, movement of the interim product through various processes and stages, and intervals of time provided for completion of activities not shown explicitly. Figure 1 shows a typical block network. Note that the network is not to scale since some activities shown may vary for given blocks.

Developing the network involves the balancing of several factors. Every activity or relationship in the individual network will be duplicated a number of times in the project network. For example, a 40 activity network used with 300 structural blocks will result in a project network of 12,000 activities. Excessive detail can lead to problems with file size, software constraints, processing time, report sizes, and so on. Activities that should be included are those which are required to establish schedule dates, schedule durations, utilization of critical resources, and those activities whose schedules will need to be tracked as the project proceeds.

Standard durations which exceed normal operational times for a given set of activities provide a means of absorbing delays, uncertainty in work content and work rate, correction of minor material problems, etc. Given the uncertainties which often prevail in the shipbuilding environment, this conservative approach makes sense for any area facing significant material problems, unplanned work, or uncertainties in work scope or sequence. It provides a means of minimizing the schedule impact of deviations from the plan, and works in conjunction with an iterative approach to planning.

Standard durations which exceed operational times also have several

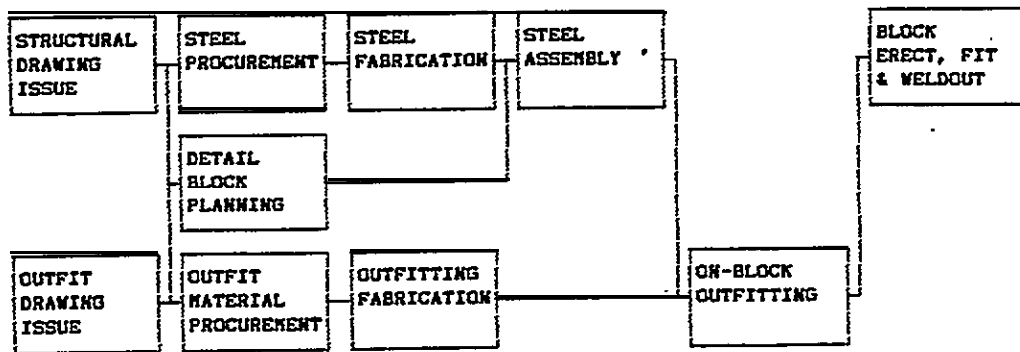


Fig. 1: Typical block scheduling network (precedence diagramming method)

disadvantages. First, line of balance scheduling of critical resources must be done separately using planned operational durations. Line of balance scheduling assumes that a crew moves from one job to the next, maintaining a smooth flow of work. Schedule durations which exceed the time required to perform the work will result in a delay between completion of one job and starting of the next if the jobs were scheduled end-to-end.

Second, longer overall program schedules may result. If the duration of an activity which is on the critical path exceeds the actual duration required, then the schedule based on that path will be longer than necessary. This can have local and/or global impacts on the project schedule. For example, if limited pin jig laydown area exists for assembly of curved shell blocks, the total time required to assemble all curved shell blocks will depend on how long each block must remain on the pin jig. This may or may not affect the overall ship construction project schedule.

Third, conservative scheduling durations imply acceptance of a certain level of schedule uncertainty. Variances in actual durations and schedule performance are hidden. Underlying problems which cause the variances are accommodated. The urgency of correcting such problems is thus reduced.

A pragmatic approach is needed to balance these considerations. Conservative (longer) scheduling durations can be used where required. If the resulting schedule does not appear optimal from any standpoint, shorter durations can be substituted and the schedule recalculated.

Hull Block Breakdown

The hull block breakdown establishes the list of blocks, their numbering, and locations of the erection breaks. This

information can be used in conjunction with contract guidance or other drawings in establishing block types and estimates of work content. These estimates can be used to define schedule durations and offsets for those activities and relationships which are non-standard and depend on the individual characteristics of the block.

Hull Block Erection Schedule

The hull block erection schedule establishes the need dates for the end assemblies, the outfitted structural blocks. This schedule is the backbone of that portion of the production schedule related to hull blocks. Any change to the erection date for an individual block is likely to affect every other activity for that block.

The erection schedule can either be in the form of a table of dates or can itself be a form of network. Figure 2 shows a portion of an erection schedule in network form. If the erection schedule is in tabular form (with no dependencies between erection of individual blocks) then the final project network will be composed on a series of independent subnets, one for each block.

Table of Schedule Offsets and Schedule Durations

The table of schedule offsets and schedule durations captures all of the non-standard features of the individual block networks. For example, assembly durations may vary by block type (flat deck or bulkhead vs. curved shell block) and/or by work content (tonnage or weld footage). Outfitting durations and routing may depend on the paint requirements and outfitting work content. A table of values matching block number with the particular values will be used to tailor the standard block network to the requirements of the specific block.

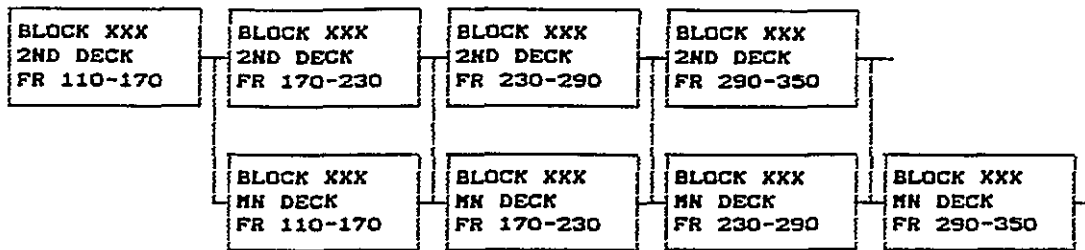


Fig. 2: Portion of an erection schedule (precedence diagramming method)

Group Technology can be used to advantage by defining families of blocks by type. For durations and offsets which are a function of some categorization by block type, the duration or offset can be provided for each block type in a separate table. The type associated with each individual block is then indicated in the block table. This encourages standardization, with the usual benefits.

BUILDING THE PROJECT MODEL

An integrated scheduling network is constructed from the elements discussed above. The network is created through the following series of steps:

- o make a copy of the block network for each individual block
- o incorporate constraining factors such as erection date into the individual block networks
- o incorporate block parameters which are unique or which depend upon some categorization into the individual block networks
- o introduce the relationships which represent dependencies within the erection schedule
- o add other activities and relations which form portions of the total project network

Each of these steps will be discussed in more detail.

Copies of the typical block network form the bulk of the overall schedule. Making the copies is straightforward with most project management software packages. It is also usually very tedious and time-consuming if more than a few copies need to be made. First, one or a group of block networks are copied. Next, the copied activities are renamed or renumbered so that all activities and relations are uniquely identified. Finally, copies are merged into a larger project network.

Many project management software packages allow definition of "hammocks." A hammock is a group of activities and relations which form a sub-network having single entry (start activity) and exit (complete activity) points.

Hammocks can be incorporated in the project network by establishing a relation to these entry and exit points.

The hammocking feature of the software can sometimes be used for incorporating standard sub-networks (such as the block subnet discussed above) into the project network. In some software packages, however, hammocks are represented by a single activity. In this case, it is not possible to tie a relation to an activity internal to the hammock. More flexible methods of incorporating standard subnets are sometimes required.

The next step in building the project network is to incorporate any necessary constraints into the project network. For example, each block has an erection or grand-block erection date. If the erection schedule has been developed by hand off-line, the erection date is a fixed date. This implies that other activities for that block (e.g., steel assembly, on-block outfitting) should be scheduled to complete in time to support the scheduled erection date. The erection date could then be represented as a milestone date for the block, as the late start of an activity (erect, fit and weldout), or as the late complete date of an activity (erection).

At this point the project file is composed of individual block networks, each of which may have a constraining start or complete date on at least one activity. The next step is to tailor the individual block networks to account for known differences. These differences may be due to individual characteristics of the block, or to characteristics common to a family of blocks. For example, the erection date is different for each block. In the case of individual differences, use values from a table of schedule dates, durations, or offsets.

Characteristics may also vary according to block type. Sets of blocks may be organized into "families" or "groups" based on some common characteristic. As an example, all blocks built in a particular jig may form a family having identical assembly durations. In this

case, one needs a table that identifies which blocks are members of the family, and another table which identifies the assembly duration for that family.

Relations which represent the predecessor-successor dependencies within the erection schedule can now be introduced. If the erection schedule is typically developed by hand, this step may be unnecessary. However, introduction of the computer as a scheduling support tool may provide opportunities for further refinement of schedules. This will be discussed later.

The last step in the process is to merge the completed block network with networks which represent other portions of the project. For example, it may be useful to include landing of major equipment and installation of key components in the overall project network. The installation schedule for propulsion machinery and shafting is directly related to the erection schedule and also to the critical path of the project. Including these relations within the scheduling network insures that they are not ignored when schedule changes are being considered.

SCHEDULING AND RESOURCE SCHEDULING

The network is at this point complete and can be scheduled. For the purposes of this discussion, critical path scheduling will be done using the Precedence Diagramming Method (PDM). Those not familiar with the concepts and techniques discussed are referred to the many excellent texts in the field.

Project start and complete dates, scheduled milestones, and planned activity start and complete dates are the constraints which limit the schedules for other activities. Most current software packages employ a two-pass scheduling approach. During the forward pass, successors of already scheduled activities are in turn scheduled, with the dates stored in the early start and early finish date fields. During the backward pass, predecessors of scheduled activities are themselves scheduled, and the dates stored in the late start and finish date fields.

Each activity then has early and late start dates, and early and late finish dates. Activities cannot be started prior to the early start, or later than the late start without either violating the project network logic, or affecting the overall project schedule. The early and late dates thus define the schedule "window" within which an activity can be worked without affecting the overall project. Each activity has float, which measures how much the activity schedule

can move within the schedule window without affecting the overall project.

If resource and capacity constraints are ignored, the late start and complete dates provide a workable schedule produced by back scheduling. This is similar to the schedule which results from scheduling back from end assembly completion dates down through a bill of materials explosion, taking proper account of durations and lead times.

The typical shipbuilding practice of back scheduling produces a schedule where every activity is on the critical path. This is equivalent to the situation that exists when the early and late start dates are the same -- there is zero float. Assuming durations are accurate, a one day delay in starting an activity will result in a one day delay in every successor activity. Given the unpredictability and frequent delays which exist in a shipyard, a more conservative approach to scheduling is useful.

Taking into account resource and capacity constraints, neither the early or late schedules are optimal. Neither results from any consideration of resource availability or levelling. High labor content and expensive shipyard facilities demand something more. Typically, some resources are critical, and constrain other schedules. Utilization of steel assembly facilities and manpower normally require careful levelling.

Many current project management software packages allow levelling of resources. One of two different algorithms is usually involved. The first is schedule constrained. Activities are progressively scheduled based on some assignment of priority (e.g. amount of remaining float for the activity). When this would result in starting an activity later than its late start date, the date constraint takes precedence and the activity is scheduled to start. This may result in resource utilization in excess of resource availability.

The second method also proceeds by progressively scheduling activities based on priority. Resource requirements are matched against resource availability curves. When a resource required by an activity is unavailable, the activity is delayed until the resource becomes available. Project completion dates will not be met if the start of an activity is delayed past its late start date. Scheduling proceeds staying within the bounds of the resource availability curve at the expense of schedule.

The resource scheduling features of project management software can be used to limit use of critical shipyard resources to within a capacity constraint or planned resource availability. The steel assembly schedule is a prime example. Manpower availability curves can be used to schedule steel assembly to maintain planned levels. If a special jig is to be used, a jig availability curve can be added to the resource file. Steel assembly records for those blocks to be built in the jig have the jig resource requirement added. If there is one jig, and it can hold only one block at a time, the resource file must show that one unit of resource "jig" is available, and the block file must show that one unit of resource jig is required. Pin jig areas can be divided up into a number of unit squares, and the number of unit squares required for the assembly of any given block or block type loaded to the project file. The total amount of available pin jig area can then be used to control the scheduling of assembly work through the area.

Once the critical resources have been scheduled, the resulting schedules should be examined carefully. Project management software is a scheduling aid, not a replacement for good planning. The software facilitates balancing of a large number of schedule and resource constraints, and examination of resulting schedules from a number of perspectives. Resource utilization curves should be examined closely. A sampling of the block schedules should be done to insure accuracy, and that the results make sense.

If problems are identified with the schedules and resource curves that resulted, adjustments can be made by hand to the schedule, and the schedules recalculated. "What-if" games can be played using copies of the network. The result should be a schedule which is logically consistent and which makes good use of key resources.

GENERAL COMMENTS

Existing project management software typically forces the user to work in a bottom-up fashion. Building a project network for a large shipbuilding project becomes a significant clerical effort. One loses sight of the overall project in the process of entering and maintaining 10,000 activity records, with associated predecessor-successor relations and resource requirements.

Building the project schedule should be a mixture of bottom-up and top-down scheduling techniques. Bottom-up scheduling can be employed to develop

those portions of the scheduling network for which a good history is not available, portions for which the available history does not meet current objectives, or portions which are known to be critical to the overall program schedule. Top-down techniques can be used where schedules have already been developed, where good historical information exists, or where the detailed schedule will not effect the overall program schedule.

The network will never completely model reality. The project management team must find the level at which the model is most useful in relation to the effort required to construct and maintain the model. The Group Technology approach outlined above simplifies the problem to one of standard families of assemblies, and instances of the standard. In addition, several strategies exist to make the effort more productive:

- o focus attention on activities which are critical to the overall project, schedules that are drivers of other schedules, and resources that are bottlenecks
- o avoid inclusion of activities for which schedules can be easily derived as offsets from the other schedules, and which are not themselves schedule drivers
- o be relentless in identifying standard durations, sequences, and categories -- look for families of components at all levels in the product hierarchy
- o develop a library of standard subnets
- o keep the project model as simple as possible, avoid unnecessary detail in the network, look for ways to reduce the size and complexity
- o where repeatability or predictability of schedule is low, more conservative scheduling approaches should be used -- longer durations to minimize impact of schedule delays
- o engineering and materials schedules can be frozen after initial development by copying the appropriate dates into the planned start and complete fields, or by keeping a copy of "the baseline" from which to run reports

The job of managing the network can become very unwieldy. If one has only 20 activities for each of 300 steel assemblies or other interim products, one has a network of 6000 activities (20 activities/product x 300 products = 6000 activities), plus the associated relations between activities. For some

packages which run on personal computers, networks of 5,000 or more activities can stretch the limits of available disk storage, and result in very long run times (30 minutes or more) for the scheduling operation. The network should contain only those activities necessary to preserve the schedule relationships and the offsets between activities.

Another method for reducing complexity in scheduling is to choose an appropriate time frame. Most project management software allows scheduling at a daily or even hourly level. But a weekly schedule may be more meaningful because it focuses attention at the proper level of detail. Scheduling by week can be done by setting durations and lag periods as multiples of 5, ignoring holidays, and setting all fixed start dates on Mondays, all fixed completion dates on Fridays.

The scheduling network can also be simplified through reducing the number of relations. If the supervisor in the field will exercise his own discretion in the scheduling of an activity between two milestone dates, then the only relations needed for that activity are those which tie it to the milestones. There is no need to add additional relations to the network to constrain the timing of the activity. Also, if simple finish-to-start relations will establish the desired work sequence, there is no need to establish a complex pattern of start-to-start and finish-to-finish relations and associated lag periods.

The schedules produced using project management software are dynamic. A single small change has the potential of changing the entire project schedule if it lies on the critical path. Once the initial schedule has been developed, it may be desirable to lock in certain schedule dates. Changes to engineering and materials schedules may cause unnecessary disruption and may impact vendors and subcontractors.

Several techniques are available to stabilize portions of the project schedule. The project schedule can be archived, and the archived dates used for scheduling selected activities. Schedule changes which conflict with the archived dates can then be handled on an exception basis. Some software packages allow preservation of the initial dates as baseline dates for each activity. The baseline dates can be used where desired, and reports produced to indicate activities having dates which are in conflict with the baseline dates. A third alternative is to copy the desired dates into the planned start and planned complete fields. When the project is rescheduled, activities whose

dates conflict with these planned dates will be shown as having negative float.

CONCLUSION

This paper outlines a method for developing the Master Production Schedule for a shipbuilding project using PC-based project management software. Currently available software offers functionality, power, and flexibility to PC users. The technique outlined here balances use of top-down and bottom-up scheduling techniques. They are designed to facilitate effective use of Project Management software in the shipbuilding environment.

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